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FINAL REPORT

Probing Neutron Star Evolution with Gamma Rays
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The research sponsored by this grant was conducted in two fields of high-energy astrophysics: gamma-ray bursts and evolution of neutron stars. It is unknown at this time whether they are related. The work performed in each area is discussed in turn below, followed by a full list of publications supported by the grant.

1 Gamma-ray bursts

On the strength of one year of BATSE data, the nearby neutron star paradigm for the origin of gamma-ray bursts was abandoned almost instantly. The most straightforward interpretation of the BATSE data (a cosmological distance scale) was not accepted widely, in my view largely because of its radical departure from past views. A galactic halo distance scale, in which gamma-ray bursts are in the outer reaches of our Galaxy but carefully construe their observed properties to cover up their ancestry, has emerged as the main competitor to the cosmological origin.

My research (with E. Fenimore, L. Lubin, B. Paczyński, and A. Ulmer) has focussed on devising tests that could distinguish between these distance scales using the avalable data. In the first instance, the issue was whether the early BATSE peak flux distribution could be used to extract more than just a slope of the $\log N(>P)$ distribution, and whether it joined smoothly to the steeper peak flux distribution of bright bursts. To this end, we analysed the peak flux distribution for the presence of a change in slope. This was done both by fitting models with a core radius to see whether a significant value for it could be found, and by developing a completely model-independent test to search for slope changes in arbitrary distributions that are nearly power laws. A slope change was marginally detected in the first-year BATSE data; by now it is of course glaringly visible in the much larger burst sample that has been accumulated.

If gamma-ray bursts are at cosmological distances, we would expect to detect effects of redshift in the dimmer ones. When time dilation (an increased average duration of bursts with decreasing brightness) was detected, we devised a test to distinguish between a truly cosmological origin of this phenomenon and a class of alternative explanations assuming a nearby population (e.g. a galactic halo) with an intrinsic anti-correlation between luminosity and duration. Through selection effects, the latter would also show a time dilation in the detected bursts. The test is based on the fact that the cosmological time dilation preserves the shape of the duration distribution at each brightness, because all durations are simply multiplied by the same redshift factor. The test was applied to the BATSE catalogue, and comes out in favour of the cosmological interpretation. More rigorous versions of the test, using raw data as a starting point, support this conclusion, albeit that care has to be taken to eliminate competing effects and selection biases.

2 Neutron stars

Good progress has been made in understanding the evolution of neutron stars and their magnetic fields. Having shown in earlier work that magnetic fields in some neutron stars, particularly Her X-1, do not decay spontaneously on million-year time scales, we (D. Bhattacharya, J. Hartman, F. Verbunt, R.W.) set out to check whether such spontaneous decay was needed in isolated radio pulsars, as claimed by many. We found that it is not; rather long decay times or no decay are preferred. Since there are neutron stars with low magnetic fields, one must conclude that there is something in their past that distinguishes them from most pulsars. These so-called recycled pulsars are in binaries much more often than normal pulsars. My research concentrates on the class of scenarios in which the recycled pulsars are initially the same as ordinary high-field radio pulsars, and have acquired their properties due to mass transfer processes in binary stars. This links their evolution to that of X-ray binaries.

One question of recent interest is that of the orbital evolution of close binaries. Various non-standard scenarios for linking low-mass X-ray binaries and recycled pulsars such as irradiation-driven evolution were proposed to explain e.g. why some recycled pulsars have no binary companions. When the orbit of the 'black widow' pulsar PSR 1957+20 was found to be shrinking, contrary to standard model expectations, this was held by some to confirm such non-standard scenarios. I showed that the magnitude and time scale of the observed variations in orbital were similar to those seen often in cataclysmic variables and RS CVn binaries and on those grounds questioned the secular nature of the observed orbital shrinking in 1957+20. Indeed, its orbital period derivative changed sign after a few years. Likewise, the shallow eclipses in PSR 1718–19 are best explained by analogy with RS CVn binaries: they are due to a wind from the companion star which is induced by enhanced stellar activity, not by any kind of evaporation by the pulsar. Hence B. Paczyński and I argued that many phenomena seen in neutron star binaries are adequately explained as due the same processes that occur in any close binary with a late-type companion and are probably due to the convective activity in the envelope of the companion.

If recycling is caused by mass transfer, it must occur also in high-mass X-ray binaries. Direct evidence for this is provided by the field strengths of pulsars like 1913+16 (the Hulse-Taylor binary pulsar), which are thought to have descended from massive binaries and have magnetic fields intermediate between the classical recycled pulsars and young radio pulsars. This can be explained by mass transfer induced recycling, but not if the amount of field decrease is simply proportional to the amount of accreted mass. It is possible that the only non-pulsing high-mass X-ray binary, 4U 1700–37, is such a mildly recycled object. With G. Brown and J. Weingartner I investigated the alternative that it is a black hole with a mass only just above that of neutron stars. Such objects should exist in significant numbers if the equation of state of neutron stars is soft, as is indicated by some evidence both from nuclear physics and astrophysics.

3 List of publications supported by the grant

1. Bhattacharya, D., Wijers, R. A. M. J., Hartmann, J.-W., and Verbunt, F.: 1992, 'On the decay of the magnetic fields of single radio pulsars', *Astron. Astrophys.* **254**, 198–212

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5. Wijers, R. A. M. J. and Lubin, L. M.: 1993, 'Is a data set distributed as a power law? A test, with application to gamma-ray burst peak brightnesses', *Astrophys. J.* **432**, 207–212

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